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Draft Report

Design Survey and Assessment of Cleanroom Energy Analysis Tools

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Research Available Analysis Tools

The limitations of existing tools used to design and analyze HVAC systems for cleanroom facilities were investigated by LBNL. Design and operation of these HVAC systems and the energy required to operate them are key issues in cleanrooms. The applicability of publicly available or commercially available models for assessing the energy performance of specialized and laboratory type facilities, such as cleanrooms was unclear. LBNL designed a survey to investigate current practices in use by a number of leading design firms specializing in design of cleanroom facilities. Design firms were contacted to obtain agreement to participate in the survey and determine the appropriate contact individual. Not all firms contacted chose to participate in the survey and some that agreed to respond requested anonymity. Surveys were then sent to knowledgeable engineers experienced in cleanroom HVAC design for the firms that agreed to participate. Eight responses were eventually received. The assessment of the responses is discussed below. In some cases further clarification of the responses was required so additional contact with the respondents was made.

The survey (figure 1) was intended to determine the design and analysis practices currently in use by each of the design firms and /or individuals. It was also designed to investigate whether the program in use was adequate for energy analysis as well as system sizing. The survey asked the respondents to identify the tools they use for energy analysis and their applicability to cleanroom applications. Through a series of questions we sought to identify features that needed improvement or other enhancements that they would like to see.

A matrix was developed to tabulate the results of the survey (figure 2). The results indicated that most of the responders utilized the Trane Trace program. While most responders desired some enhancements to the program, in general their responses indicated that it was adequate for the level of accuracy needed in their work. Models for cleanroom systems were perceived to be adequate. One respondent commented that a more significant problem is being able to predict the process loads with any degree of accuracy at the stage in the design when the systems are being sized. The accuracy of the design and analysis tool (ie: Trane Trace for most designers), perhaps accurate to within 10-20% with adequate assumptions, is acceptable given that the load assumption could vary from the actual load by 100%.

Generally, the responses indicated that the economics of energy analysis is not of major concern to the designers. Some designers were not aware of the economics capability in the program they use. The low priority given to energy analysis is consistent with the views held by many in the industries that utilize cleanrooms. There is a focus on speed in bringing new products to market that often precludes spending time to evaluate energy saving alternatives. Since energy cost is a minor component compared to the process costs, building owners may not emphasize this aspect to their designers.

The responses confirmed the broad use of the Trane Trace program combined with simplified spread sheet analyses. Typically, designers develop their own spread sheets to model the cleanroom systems, and this, they consider, is sufficiently accurate for design. This is due to the fact that most cleanrooms operate in steady state condition. Most are operated continuously with little variation in the room's internal heat gain. Heat gain primarily originates from the process equipment ("tools"), recirculating air systems, and lighting which are all relatively constant. For more conventional areas of the plant, the Trane Trace program, which models more typical building elements, is used.

Cleanroom Energy Analysis Tools

Although Trane's Trace is a popular program among cleanroom designers, it is not in the public domain and the modeling algorithms are not available. In fact we understand that due to high staff turnover of programmers of this software, at least some of this program is a "black box" even to Trane. Therefore, we have focussed our effort on DOE-2, the most widely used and best documented public domain building energy simulation tool.

Despite it's robustness, DOE-2 has shortcomings relative to modeling the unique HVAC systems and configurations found in buildings for high tech industries. We have completed a review of these shortcomings and these are summarized below:

- 2 distinct systems cannot serve a singe zone. DOE-2 allows only one system type to serve each zone. This limitation does not pose a problem in modeling a HVAC system serving a conventional building. However many cleanroom HVAC designs have multiple systems serving a single zone: for make-up air and for recirculation air. Because of cleanliness requirements, air in a cleanroom space needs to be recirculated at a higher rate than fresh air makeup or temperature and humidity conditioning requires.

- 2 different chilled water loops at different temperatures cannot be modeled.

- Exhaust air schemes are quite limited.

- Airflow rate limits for some system types

Options to overcome shortcomings of DOE-2 include the following:

1. **DOE-2 input adaptations.** This is the approach used by LBNL in developing a cleanroom model in its simulation of base case and energy efficient case cleanroom for California (see Busch, J., "Cleanroom of the Future: An Assessment of HVAC Energy Savings Potential in a Semiconductor Industry Facility," LBNL Report No. 41356, March 1998). In the DOE-2 simulations performed in this study, the approach used was to define a "dummy zone" that was tiny and without any loads and to use that zone as a work around of the one system per zone restriction. The dummy approach was used in 2 different ways to model 2 different cleanroom HVAC configurations. In one case, the system was modeled as a Power Induction Unit, and induction air came from the dummy zone. In a second case, the recirculation system

(Single Zone Reheat Fan System in DOE-2 parlance) with no *direct* outside air was specified for the cleanroom zone. The make-up air system (Constant Volume Reheat Fan System) was specified for the dummy zone, with all the flow directed to the cleanroom zone via the "Outside-Air-From-System keyword in DOE-2.

While this approach to modeling cleanrooms with DOE-2 produces reasonable results and enables one to analyze the energy performance of different HVAC components and designs, it is less than ideal to have to use a work around that is cumbersome and would be difficult to transfer reliably to other users.

2. **Web-based interactive front-end tool, interfacing with DOE-2.** A partial solution to the above problem of making the DOE-2 cleanroom model transferable is to build a "front-end" for it similar to that used for residential housing with LBNL's Home Energy Saver (HES). Such a solution might allow a designer or analyst to modify certain inputs and see certain outputs without having to learn either DOE-2 or the work around for cleanroom HVAC systems. Furthermore, it could be web-based like the HES so it could be updated continuously without dealing with the need to upgrade a dispersed user base. It could also potentially use the same or similar technology as the HES for managing the user interface and calculations.

   A technical description of the HES follows:

   > The Home Energy Saver < http://HomeEnergySaver.lbl.gov > is a website centered around a web-based energy calculator. It provides customized estimates of residential energy use based on building description information provided by the user. The site also includes decision-support information and extensive links to related web sites.
   >
   > All energy end-uses are simulated based on standard energy engineering and thermodynamics principles. Heating and cooling energy use is simulated using the DOE 2.1E calculation engine, and all other end uses are simulated using algorithms and data developed at LBNL. Logic for determining default values, etc., was developed at LBNL.
   >
   > HES as a website can be served from any webserver to any web browser. The interactive portion was built on and for an Apple Macintosh, but can also run on IBM PC or any UNIX machine. The underlying database runs on a MAC but could be any ODBC-compliant database. The DOE-2 calculation engine runs on an IBM PC but could run on a UNIX machine. The SEND.CGI that handles IO for DOE-2 can only run on Windows NT/IBM PC. The site runs on the Apple MacOS 8.5.1, except for DOE-2 and SEND.CGI which use a Windows NT Server, all "off the shelf."
   >
   > The programming languages used were:
   >
   > - Web pages–HTML & JavaScript.
   > - Interactive forms–Tango & SQL.

- CGI–Visual Basic.

Site usage is limited by amount of RAM (currently 250 concurrent connections using 350MB RAM). Speed of Interactive forms limited by CPU and network speed (400MHz [webserver], 266MHz [DBMS], 100-BaseT [net]). SEND.CGI & DOE-2 limited to one user at a time. The main HES server is mirrored for enhanced reliability.

This is the most well-validated and well-documented residential energy calculation framework. It provides the most extensive decision-support features of any comparable tool. HES is available internationally via the Internet, without the need for traditional software distribution/installation. It requires Internet access and a forms- and frames-enabled web browser.

Related and Auxiliary Software used during or in support of construction includes:

- CGI–Visual Basic.
- DOE 2.1E (developed at LBNL).
- Pervasive's Tango Editor developed the interactive forms.
- StarNine's WebStar web server.
- Pervasive's ButlerSQL is the DBMS.
- Adobe PhotoShop.
- BBEdit, and MS Excel were also used.

Any frames- and forms-enabled web browser, on any platform, can use this site. Memory and RAM limitations are as dictated by the browser software.

User sessions require less than 1 minute for simplest user level; up to 60 minutes for advanced/detailed user level.

A cleanroom interactive front end tool might query the user for the following parameters:

- floor area and enclosed volume of cleanroom space (bdl would assume an isolated adiabatic box that only interacts with outside air through the HVAC system)
- internal loads
- HVAC system - choice between 2 general system types
- airflow rates for supply air, outside air, exhaust air
- static pressure of supply air
- chilled water temperature
- some hvac component choices such as fan type and efficiency, cooling tower type, chiller type, and efficiency.
- utility rates

Users might like to see outputs presented in appropriate graphic and tabular forms of the following:

- energy cost
- total energy consumption and annual peak demand
- end use energy consumption
- monthly energy consumption and peak demand
- binned temperature and humidity plots
- echo of user inputs/assumptions

3. **Modifications to DOE-2 code**. DOE-2 is no longer in development beyond maintenance of the current version 2.1E. It is highly unlikely that such large modifications would be possible.

4. **Incorporate cleanroom type HVAC system configuration capability into next generation tool, EnergyPlus.** EnergyPlus is a new-generation building energy simulation program based on DOE-2 and BLAST, with numerous added capabilities. The program is in development and not expected to be released until sometime in 2000.

   EnergyPlus is being designed to handle some of the major shortcomings of DOE-2 with regard to modeling cleanrooms. First of all, it will be able to handle multiple systems serving a single zone. Multiple chilled water loops operating supplying cooling coils at different temperatures will also be a built-in option. Exhaust air will able to handled with intelligent scheduling based on control parameters.

   Excerpts below (from *Building Energy Simulation User News*, Vol. 20, No. 1, Spring 1999) describe the basic elements of EnergyPlus germane to cleanrooms HVAC modeling:

   > The major change in EnergyPlus is that integrated simulation is the underlying concept-loads calculated (by a heat balance engine) at a user-specified time step (15-minute default) are passed to the building systems simulation module at the same time step. This is in contract with DOE-2 and BLAST approach which is sequential simulation-loads, systems, plant, and economics run for the full period each, one after the other. The building systems simulation module, with a variable time step (down to seconds), calculates heating and cooling system and plant and electrical system response. Feedback from the building systems simulation module on loads not met is reflected in the next time step of the load calculations in adjusted space temperatures if necessary.
   >
   > By using an integrated solution technique in EnergyPlus, the most serious deficiency of the BLAST and DOE-2 sequential simulations can be solved-inaccurate space temperature predication due to no feedback from the HVAC module to the loads calculations. Accurate prediction of space temperatures is

crucial to energy efficient system engineering-system size, plant size, occupant comfort and occupant health are dependent on space temperatures.

Integrated simulation models capacity limits more realistically and tightly couples the air and water side of the system and plant. Modularity is maintained at both the component and system level. This eases adding new components and flexibly modeling system configurations and, at the system level, equipment and systems are clearly connected to zone models in the heat balance manager. To implement these concepts, we use loops throughout the building systems simulation manager -- primarily HVAC air and water loops. Loops mimic the network of pipes and ducts found in real buildings and eventually will simulate head and thermal losses that occur as fluid moves in each loop. As mentioned earlier, EnergyPlus has no hardwired "template" systems. Instead, we developed input file templates for the each of the major system types in BLAST and DOE-2. These templates provide an easy starting point for users with system configurations that differ from "default" configurations. The air loop simulates air transport, conditioning, and mixing and includes supply and return fans, central heating and cooling coils, heat recovery, and controls for supply air temperature and outside air economizer. The air loop connects to the zone through the zone equipment. Zone equipment includes diffusers, reheat/recool coils, supply air control (mixing dampers, fan-powered VAV box, induction unit, VAV dampers), local convection units (window air-conditioning, fan coil, water-to-air heat pump, air-to-air heat pump), high temperature radiant/convective units (baseboard, radiators) and low temperature radiant panels.

For the air loop, the solution method is iterative, not single-pass as in DOE-2 and BLAST. In order to specify equipment connections to a loop, nodes are defined at key locations around the loop with each node assigned a unique numeric identifier. Node identifiers store loop state variables and set-point information for that location in the loop. We use an iterative solution technique to solve for unknown state variables along with control equation representations. These representations connect the set points at one node with the control function of a component, such as fan damper position and cooling coil water flow rate. In this schema, all the loop components are simulated first, then the control equations are updated using explicit finite difference. This procedure continues until the simulation converges. Typical control schemes are included in the input file templates described earlier.

There are two loops for HVAC plant equipment-a primary loop (for supply equipment such as boilers, chillers, thermal storage, and heat pumps) and a secondary loop (for heat rejection equipment such as cooling towers and condensers). Figure 7 presents a schematic view of equipment connections on the primary plant loop. Equipment is specified by type (gas-fired boiler, open drive centrifugal chiller) and its operating characteristics. In the first release of EnergyPlus, we are supporting performance-based equipment models (such as in BLAST and DOE-2). But because of the modular code, it will be easy for developers to add other types of models. As in the air loop, the primary and secondary plant loops use explicit nodes to connect equipment to each loop. Connections between the air loop and zone equipment and the primary and secondary loops are made through the node data structure and must be explicitly defined in the input file. A similar loop approach is proposed for a new electrical loop for simulating electrical systems-supply (utility, photovoltaic modules, and fuel cells), demand (plug loads, lighting, and other electrical loads), and measurement (meters).

In the longer term, EnergyPlus users will have more systems and equipment options through a link to SPARK [BUH 93], a new equation-based simulation tool. SPARK is a better solver for complex iterative problems and is currently in beta testing. SPARK already has a library of HVAC components based on the ASHRAE primary and secondary toolkits. EnergyPlus will continue to have system types (in input file templates) but developers and advanced users will be able to easily build complex new HVAC models with SPARK.

5. **Develop SPARK module.** VisualSPARK, currently available as a stand-alone program in beta release, is capable of modeling a cleanroom environment and HVAC configuration. Though not yet tried in for these types of problems, it could in theory be set up and packaged to run cleanroom type problems. The challenge would be in managing the data input and output and making it somewhat user friendly for the cleanroom design community. As with the DOE-2 application, a web-based interactive front-end tool could be developed for SPARK as well.

Figure 1

SURVEY QUESTIONNAIRE: CLEANROOM DESIGN TOOLS
Please circle your response where appropriate.

Section I: Current Modeling Capabilities

1) Does your firm use a computer analysis model or programs (eg. DOE-2, TRACE or TRNSYS) to design or to determine the energy performance for cleanroom HVAC systems?

Yes *No* *(go to Section II: Desired Modeling Capabilities)*

If Yes, please provide its name(s):

2) Is the analysis model

a) commercially available? *b) proprietary to your firm?*

3) Does it help in sizing the HVAC equipment?

Yes *No*

4) Does it analyze the energy performance of HVAC systems?

Yes *No*

5) Is the model well documented?

(a) It has user manuals *Yes* *No*
(b) Its algorithms and methods are identified and explained *Yes* *No*

6) Have the results from this model been validated by:

a) Experiments *Yes* *No*
b) other models *Yes* *No*
c) *other methods* *Please specify:*
d) *not known*

7) What types of HVAC systems and components can it handle?

8) For cleanroom design projects, what types of HVAC systems and components does it handle poorly or not at all?

9) On a scale of 1 – 10 (1 being very good and 10 being poor), how well can it simulate the systems and component configurations you wish to design or analyze.

1 2 3 4 5 6 7 8 9 10

10) What kind of analysis does it perform?
(a) Steady State or Dynamic
(b) Performs simulation (i) hourly (ii) daily (iii) monthly (iv) other: Specify

11) Can it perform an economic analysis of energy performance?
Life Cycle Cost Yes No
Payback Yes No
Other (describe)

12) Can it handle real-world utility tariff structures and rates?
Yes No

13) What is the amount and level of detail of input data?
a) Considerable b) Moderate c) Trivial

14) What are the outputs?

a) Annual energy consumption
b) Annual peak demand for electricity
c) Annual energy cost
d) Peak loads for sizing HVAC system components
e) Performance parameters (temp, control, etc.)

15) Are input requirements matched with data availability? Does the model require input data that are not readily available to the user?

a) Perfectly-matched *b) Moderately well-matched*
c) Poorly-matched

16) What strengths or limitations of the tool stand out?

17) Other important considerations?

18) How much, if any, of the system modeling do you perform and what portions are sub-contracted?

Section II: Desired Modeling Capabilities

Desirable features/capabilities that you'd like to see in an analysis tool:

19) How detailed an analysis would you like it to perform?

20) On a scale of 1 – 10 (1 being very good and 10 being poor), how important are the following outputs from the ideal model?

( ) total estimated energy consumption
( ) energy consumption by end-use (example fan energy, compressor energy, etc.)
( ) peak energy demand
( ) operating costs (based on utility tariffs)
( ) cost-effectiveness of components
( ) sizing
( ) diversity analysis
( ) performance analysis (temp.,air flow, etc.)

21) How close do the simulation results have to be to the actual value for you to consider them acceptably accurate?

Perfect *Factor of 2 off*

Within 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

22) On a scale of 1 – 10 (1being very good and 10 being poor), how important are the following to you?

( ) Detail level of analysis
( ) Accuracy level
( ) Simplicity, easy of use
( ) Speed of calculation

23) What other software tools would you like the analysis model to integrate/interact with?

24) How much time can you afford to spend with a design and/or energy analysis tool:

a) To assemble inputs for the first simulation run?

b) To perform a complete analysis of options?

25) To what extent (% of useage) would the design and/or energy performance analysis tool be used by:

You as the A/E	________________%_____
Vendor or supplier	________________%_____
Design/build contractor	________________%_____
Total	_________100%________